Dust Mitigation for Martian Exploration

Blakeley S. Williams

Kennedy Space Center

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Blakeley S. Williams[1]
University of South Alabama, Mobile, Alabama, 36688

One of the efforts of the In-Situ Resource Utilization project is to extract oxygen, fuel, and water from the Martian air. However, the surface of Mars is covered in a layer of dust, which is uploaded into the atmosphere by dust devils and dust storms. This atmospheric dust would be collected along with the air during the conversion process. Thus, it is essential to extract the dust from the air prior to commencing the conversion. An electrostatic precipitator is a commonly used dust removal technology on earth. Using this technology, dust particles that pass through receive an electrostatic charge by means of a corona discharge. The particles are then driven to a collector in a region of high electric field at the center of the precipitator. Experiments were conducted to develop a precipitator that will function properly in the Martian atmosphere, which has a very low pressure and is made up of primarily carbon dioxide.

Nomenclature

ESP	=	electrostatic precipitator
ISRU	=	in-situ resource utilization
p	=	gas pressure [mm Hg]
d	=	electrode gap [mm]
I	=	current [μA]
V	=	voltage [V]

I. Introduction

THE Mars In Situ Resource Utilization project is primarily focused on producing rocket propellant for a return trip from Mars. The efforts of this project are aimed at extracting fuel from the carbon dioxide rich Martian atmosphere through a chemical process. Unfortunately, Mars is covered in a layer of dust and is frequented by dust devils and storms which uplift the dust into the atmosphere. This dust would not only interfere with the extraction procedure, but inhalation of the airborne dust would be considered a health hazard to astronauts within a Martian habitat. Thus, it is crucial that the dust be removed before the extraction process is commenced. An electrostatic precipitator is a device that is commonly used for industrial purposes on Earth to remove particulate matter from a flowing gas. This device could potentially be used to extract the dust from the Martian air before it is converted to sustainable resources.

II. In Situ Resource Utilization

In Situ Resource Utilization (ISRU) refers to the production of useful materials from resources that are readily available at a given location. Virtually all of the resources needed to support a manned mission are available in some manner on the surface of Mars.[1] According to the data taken from the Viking mission to Mars, the Martian atmosphere is comprised primarily of carbon dioxide (about 95%), with traces of nitrogen, argon, oxygen, carbon monoxide, and water vapor. NASA's Mars ISRU program is exploring various methods for converting atmospheric carbon dioxide to rocket propellant.

One method being considered is known as the Sabatier reaction. In this reaction, carbon dioxide reacts with hydrogen in the presence of a nickel catalyst, producing methane and water.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

[1] NASA USRP Intern, Electrostatics and Surface Physics Lab, Kennedy Space Center, University of South Alabama

This reaction is being considered by NASA for use in future manned missions to Mars, in which terrene hydrogen would be brought to Mars where advanced robotic missions would establish miniature chemical plants to convert the Mar's atmospheric carbon dioxide to methane for fuel and water for astronaut sustainability.[2]

III. Martian Atmosphere

The atmosphere of Mars poses many electrostatic difficulties due to its low pressure and dry, dusty conditions. The atmospheric pressure on Mars ranges from approximately 5 to 10 mbar. This low pressure presents vast challenges since it will greatly affect the characteristics of electrical discharges. A Paschen curve for a given gas is a graph of the breakdown voltage of parallel plates in that gas as a function of the product of gas pressure, p, and electrode gap, d (Fig. 1). As the product decreases, the sparking potential, or breakdown voltage, also decreases until, at a critical value, known as the Paschen critical value, it becomes a minimum for a given gas. At gas pressures less than the Paschen critical value, the sparking potential rises rapidly as pressure decreases.[3]

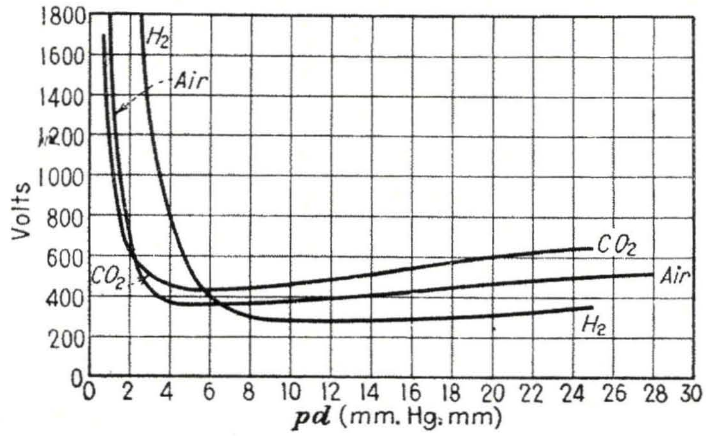

Figure 1. Paschen curve for plane-parallel electrodes (temperature = 20°C)[5]

The surface of Mars is covered in a layer of dust which has been redistributed across the entire planet due to global dust storms, which occur on average once every three Martian years.[4] The dust is uploaded into the atmosphere by these occasional storms and also by daily dust devils (Fig. 2). The uplifted dust becomes electrostatically charged by tribocharging as a result of collisions with other particles. The dust may also become highly charged from photoionization from the intense UV radiation.[6] The average diameter of the dust particles that remain suspended in the air for weeks or months have a diameter of approximately $1 - 2\ \mu m$.[4]

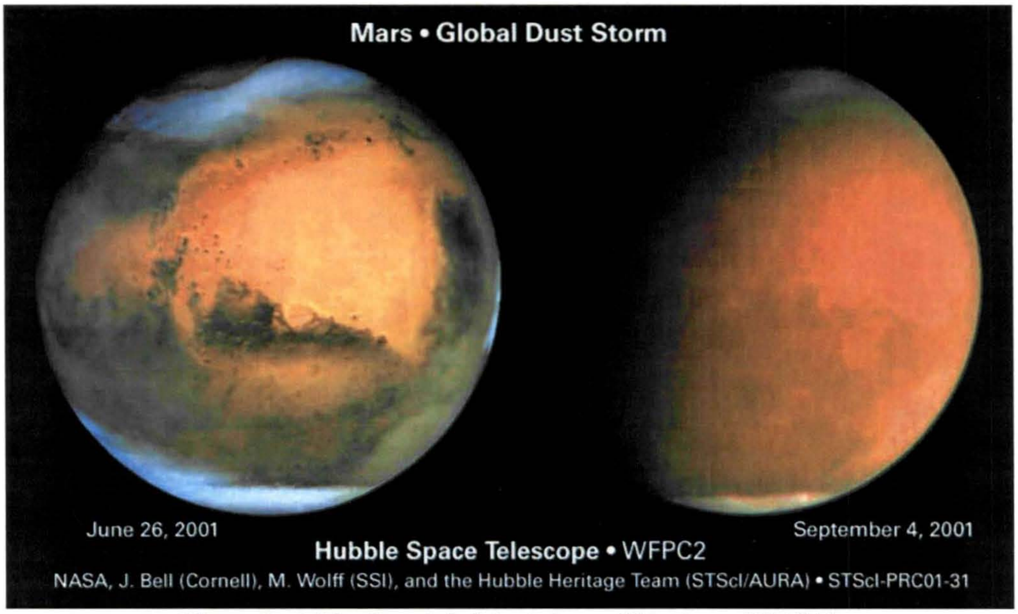

Figure 2. A Martian global dust storm. [Courtesy of NASA]

IV. Electrostatic Precipitator

An electrostatic precipitator (ESP) is a device that is commonly used in dust removal technology on earth. Precipitation is chiefly used in the removal of suspended materials from gases of many industrial applications. However, its adaptation for usage in the Martian atmosphere is not simple because the low pressure of the Martian environment will greatly affect the characteristic of electrical discharges.[7] Additionally, the Martian atmosphere is primarily comprised of carbon dioxide. ESPs are not typically operated with carbon dioxide as the medium.

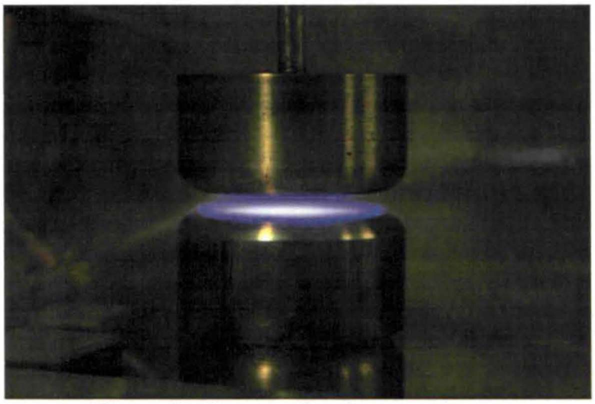

Figure 3. Corona glow between brass plates. [Courtesy of NASA]

An electrostatic precipitator is a particulate collection device that employs the electrostatic force on an electrostatic charge to remove particles from a flowing gas. Particles that are exposed to gas ions in an electrostatic field become charged and precipitate out under the action of the electric field. The precipitation process involves gas ionization and particle collection. Particle collection is achieved by producing an electrostatic field to charge the dust particles and facilitating their migration to a collection surface.[8] To achieve gas ionization it is necessary to exceed the electrical breakdown characteristic strength of the gas, thus causing a corona discharge. A corona discharge is brought on by the ionization of a fluid around a conductor. Sparking, arcing, and complete electrical breakdown are advanced stages of a corona discharge and are undesirable in ESP utilization.

A cylinder-rod setup is the ESP geometry is being considered in these tests. In this design, a rod is passed through the center of a cylindrical tube and held taut at either end by non-conductive materials (Fig. 4). To generate an electric field within the ESP, a voltage is applied to the collecting electrode, i.e. the rod. It is desirable to apply the highest workable voltage without sparking or arcing. This will maximize the effectiveness of the ESP.

In some ESPs, gas ionization and particle collection are performed in two separate steps. In the experiments discussed in this paper, these two steps were performed simultaneously. Since the Martian dust is charged through tribocharging and solar radiation, gas ionization is not a necessary step. It is suspected that the dust, which enters the ESP with a negative charge, will be a attracted to the rod, which has a positive high voltage applied to it.

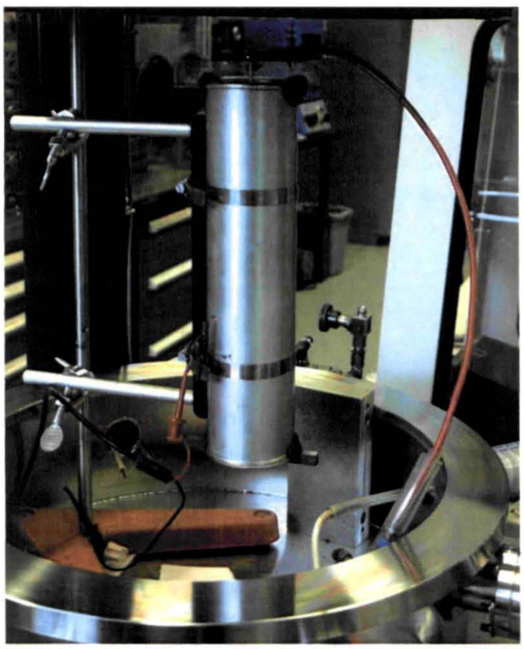

Figure 4. A cylinder-rod electrostatic precipitator.

V. Experimental Approach

The ESP design being considered in this experiment is a wire-in-cylinder design, in which a wire, or rod, is passed through the center of the cylinder and held in place at either end. In this design, the wire/rod is the collecting electrode, to which a voltage is applied, and the cylindrical wall is the outer electrode. Since air and carbon dioxide have similar Paschen curves (Fig. 1), the experiments were initially run in air for the sake of simplicity. Experiments were conducted in a vacuum chamber at 7 Torr to simulate the pressure on Mars.

Different geometries were considered for the ESP. Three cylinders of different diameters ranging from 2 to 4 inches, were considered, and also 2 rods of different diameters, ½ in and ¾ in, and a wire, 100 μm diameter, were considered, totaling 9 different geometries to be tested. The first step of data collection was to get Current-Voltage (IV) curves for all 9 geometries. With the IV curves, corona onset and streamer values were determined for each geometry. A streamer occurs when the voltage is increased and the corona glow breaks up into separate patches in which filaments rapidly appear and disappear producing a discharge from one electrode to the other. In this case, it was when the corona went from being a uniform glow along the rod to being a glow that sparked between the center of the rod and the inner cylinder wall. Additionally, as a streamer occurs, the current very suddenly increases dramatically while the voltage drops. Some geometries were immediately discounted at this stage because the range between their corona onset and streamer values was not large enough to provide a stable E-field.

The remaining geometry options were tested to see what kind of charge they could impose on a ball that was dropped through the ESP. Each ESP geometry was set up vertically in the vacuum chamber with a Faraday cup below it. With the use of a motor, a ball was lowered halfway into the cylinder (Fig. 5). At this point, the high power voltage source was turned on to a specific voltage ($\approx$80 – 90% of the breakdown voltage for that geometry). The ball was then lowered into the Faraday cup, and the charge imparted onto the ball by the ESP was read from an electrometer. This value was then compared to a theoretical charge value that was calculated.

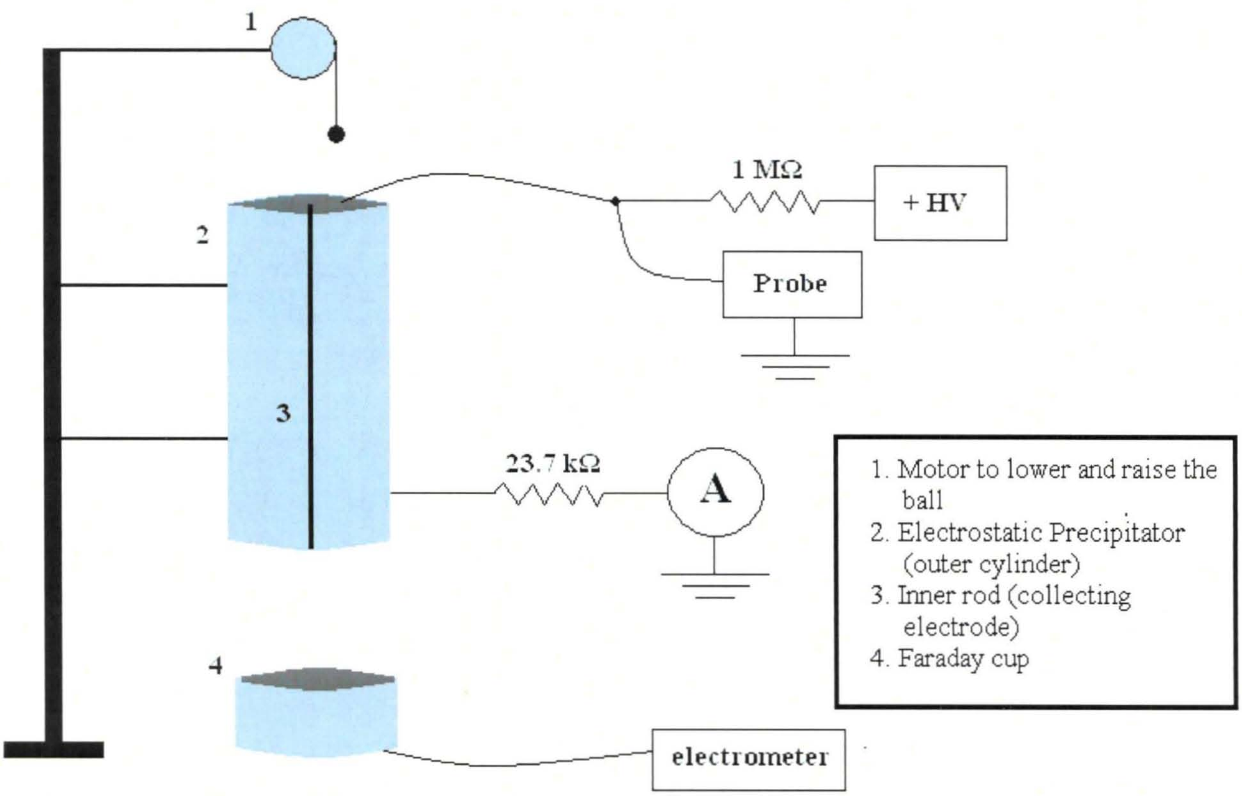

Figure 5. Schematic drawing of the experimental setup.

Once a procedure was established for determining IV curves and measuring charge, these same geometries were tested in carbon dioxide, rather than air. However, it was found that despite the fact that carbon dioxide and air have similar Paschen curves, the IV curves taken in air were not at all similar to those taken in carbon dioxide (Fig. 6). In fact, quite a few of the geometries that functioned well in air broke down immediately when tested in carbon dioxide. Neither of the rods functioned with carbon dioxide as a medium. In the IV curve for both rods, the range between corona onset and streamer values was exceptionally small. Thus, it was determined that the larger the distance between the rod and the cylinder wall, the better the range, so only a rod or wire with a small diameter could be used as a collecting electrode for an ESP in carbon dioxide. The wire presented many problems since it was

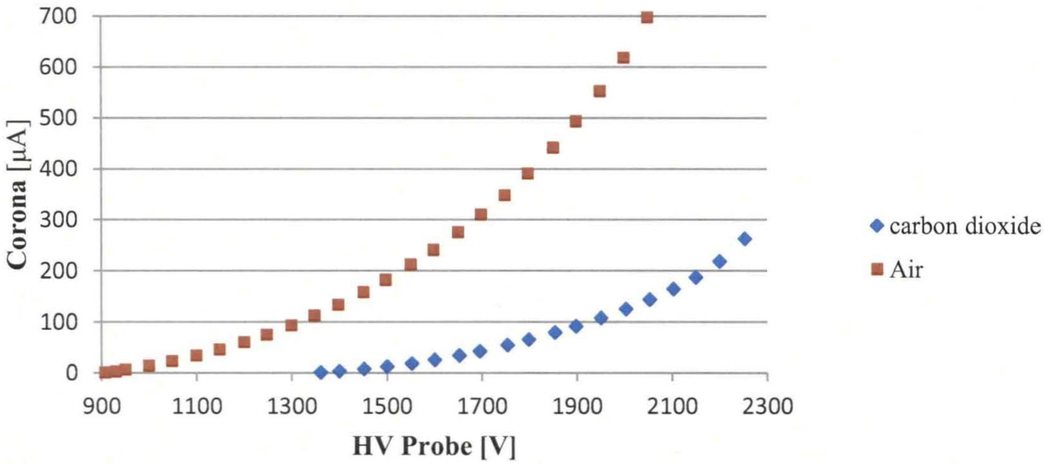

Figure 6. Comparison of IV curve generated in both carbon dioxide and air for a 4 in. diameter cylinder with a 100 µm wire collecting electrode.

fragile and very difficult to put together. Additionally, the wire would be impractical for any permanent uses, since it would be extremely difficult to remove collected dust from it without damaging the wire. At this point, a new size rod was introduced to replace the wire. A 1/8" rod was tested in the 3 cylinders. It performed best in the 3 in. diameter cylinder, where it was found to have a strong E-field and a significant IV curve range (Fig. 7).

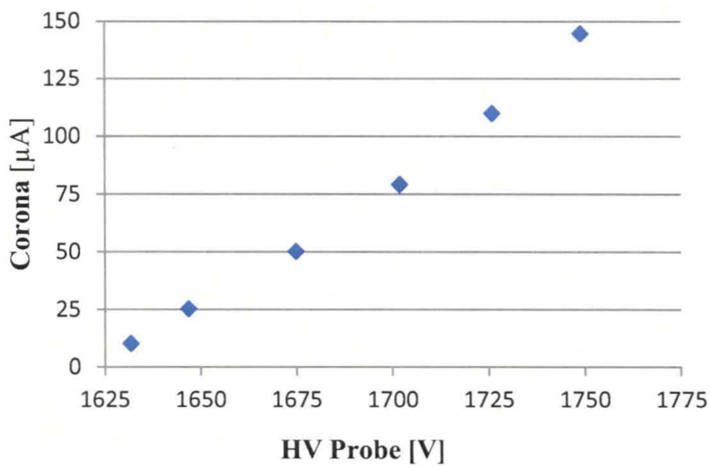

Figure 7. IV curve generated in carbon dioxide for a 3 in. cylinder with a 1/8 in. rod collecting electrode.

This geometry was deemed to be the best candidate for the ESP. At this point, testing was begun to determine the dust collecting capabilities of the ESP. Martian stimulant of size 25 μm to 45 μm was used in the testing procedure. The dust could not simply be poured through the ESP. Since the dust on Mars is in very small quantities and is aerosolized, it was important to simulate this in the testing procedure. A method was developed for aerosolizing the dust within the vacuum chamber. A glass jar was suspended upside down above the vertical ESP. A tube ran from the outside of the chamber into the bottom of the jar. The chamber was filled with carbon dioxide to a pressure of almost 7 Torr. Then, to introduce aerosolized dust into the chamber, dust was added to an opening that fed through the tube entering the bottom of the flask. A small amount of carbon dioxide (enough to reach a pressure of 7 Torr within the vacuum chamber) was blown slowly through the tube, to puff the dust into the jar, where it was aerosolized (Fig. 8). The dust would then fall through the ESP where it should be collected by the rod.

A plastic dish was placed underneath the ESP to catch any dust that was not collected. To set a baseline, dust was puffed into the chamber ten times without an E-field being applied. A significant amount of dust was collected on the dish and weighed. This value was then compared to the amount of dust collected on the dish when an E-field was applied. There was a considerable difference between the amounts of dust collected with and without the E-field applied, suggesting that the ESP was collecting the dust as it should. However, when the ESP was disassembled it was discovered that, although the dust had been collected, it had not collected on the rod. Instead large quantities of dust were found on the inner wall of the cylinder. This suggests that the dust is being charged positively by the E-field and attracted to the negative cylinder wall. Although the ESP is obviously functioning, it would be ideal for the dust to collect on the rod rather than the cylinder wall, since cleaning the cylinder wall would be a lot more challenging than cleaning the rod.

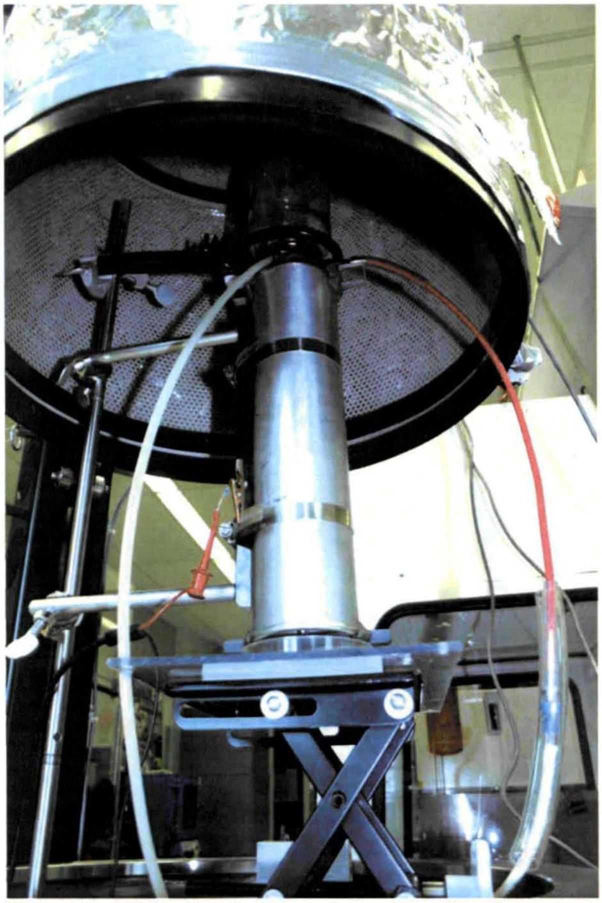

Figure 8. ESP with glass jar above it to distribute dust and plastic dish below it to collect dust.

The dust suspended in the air on Mars has a negative charge. To simulate this, the dust in these experiments should have a negative charge as it enters the ESP. Negatively charged dust that enters the ESP would be attracted to the positively charged electrode (the rod). To determine the charge of the dust, a Faraday cup was placed underneath the ESP and dust dropped into it without any E-field being applied. It was found that the dust has a slight negative charge when it enters the ESP. However, the dust is obviously being charged positively by the E-field as it enters the ESP and being forced to the cylinder wall where it is collected. Thus, the next challenge is to charge the dust negatively before it enters the ESP to simulate the dust on Mars. Most precipitators used on Earth have a precharging step as well as a collecting step. This is a concept that is now being considered for this experiment. A parallel plate precipitator is being designed to charge the dust negatively before it passes through the rod-cylinder ESP.

VI. Conclusion

The In Situ Resource Utilization efforts aim to produce sustainable resources, specifically water and rocket propellant, from the Martian air. Devices are being designed to draw in Martian air and convert it through a chemical process known as the Sabatier reaction. However, the surface of Mars is covered in a thin layer of dust which is uploaded into the air by dust storms and dust devils. Through triboelectric charging and UV radiation, the small dust particles in the air are negatively charged. To prevent the dust from interfering with the extraction process, the dust needs to be removed before the air is converted. A cylinder-rod ESP that has the abilities to function in the low pressure, carbon-dioxide rich atmosphere of Mars has been developed to collect Martian dust that passes through it. However, the dust is being collected on the inner cylinder wall rather than the positively charged rod in the center of the cylinder. This suggests that the dust which is introduced in the experiments does not effectively simulate the dust in the Martian air, since it is not sufficiently negatively charged. Future work will focus on developing a method for charging the dust negatively before it passes through the ESP, in order to better simulate Martian conditions.

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